JOURNAL
OF THE
WASHINGTON ACADEMY OF SCIENCE

VOL. II, JANUARY 19, 1912. No. 2.

GEOLOGY.—*Applied geology.*[1] ALFRED H. BROOKS.

The science of geology, generally regarded as having originated in the vague speculations of the cosmogonists hardly two centuries ago, has today become of great practical utility. During the past decade all geologic investigations have shown a marked tendency toward material problems, which is in contrast with the previous decade, when the interests of pure science were much more strongly emphasized. No one will deny that economic, or as I prefer to call it, applied geology is attracting more and more attention from professional geologists. It is appropriate that the members of this Society should take cognizance of this trend in geologic thought, analyze the conditions which have brought it about, and decide, it may be, whether it makes for the good or the evil of the science.

Before discussing this subject it will be well to attempt a definition of the term "applied geology." Some appear to believe that when the geologist emerges from the tunnel's mouth he is at once transplanted into the realm of pure science, and that the miner's candle illuminates only the so-called practical or even commercial problems. I submit that such opinions are not justified. The surveys made as a basis for geologic maps and structure sections, usually classed as belonging to the realm of pure seicnce, often yield results which are the most concrete examples of applied geology. On the other hand, the exhaustive study of mineral deposits is essential to the solution of many fundamental geologic

[1] Published by permission of the Director of the United States Geological Survey.

Presidential address delivered before the Geological Society of Washington, December 13, 1911.

problems. A close analysis will make it evident that the line of demarcation between the fields of pure and applied geology is in a large measure arbitrary. The collection today of a new group of facts or the determination of new principles relating to pure science, may result to morrow in their application to industrial problems. Mr. Gilbert has recognized two fields of geologic research, the one embracing the study of local problems of stratigraphy, structure, etc., the other, the general problems of geo-

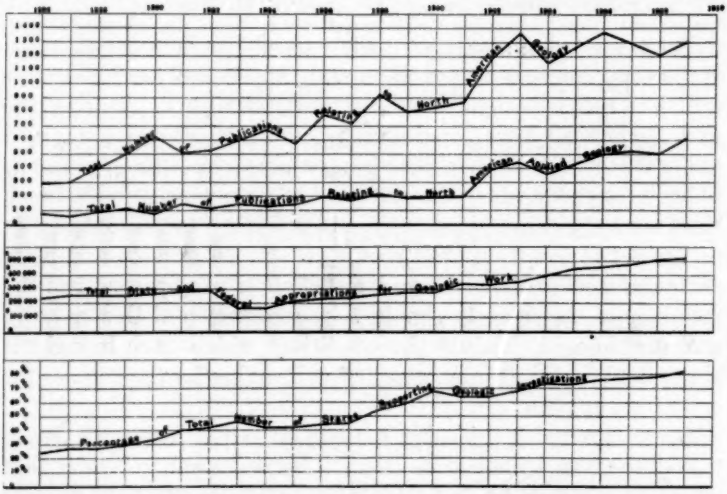
Total Number of Publications
Total Number of Publications Relating to Work
American Geology
Total State and General Appropriations for Geologic Work
Percentage of Total Number of States Supporting Geologic Investigations

Fig. 1. Geologic publications, state and federal appropriations for geologic work, and percentage of total number of states supporting geologic work for the years 1886 to 1909

logic philosophy, and has shown that both may yield results of the highest industrial importance. As David Paige has expressed it:

> There indeed can be no antagonism between science and art, between theoretical knowledge and its economic application. The practical expression of a truth can never be divorced from its theoretic conception.

If, in spite of what has been said, the two fields of science are to be differentiated, applied geology may be defined as the science which utilizes the methods and principles of pure geology to supply the material needs of man.

While the present tendency of geologic science toward the investigation of problems of everyday life is patent to all, yet it is desirable to express this tendency quantitatively. For this purpose, I have determined the percentage of geologic publications issued annually during the last quarter of a century devoted in part or entirely to applied geology. The result of this analysis is graphically presented in the diagram (Fig. 1) in which the one curve represents the total number of publications; another, those classed as bearing upon applied geology. This diagram is based on an actual count, judging by the titles, of the publications included in the annual bibliography of North American geology. It is conceded, of course, that a mere enumeration of titles is, at best, but a crude method, which neither takes into account the extent of the individual publications nor attempts to

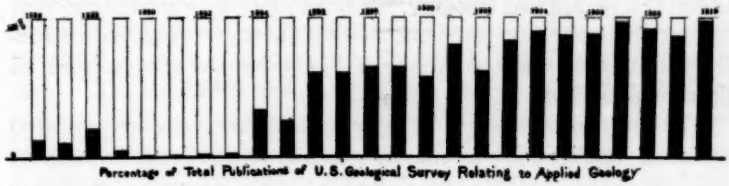

Fig. 2

appraise their value to science. However, I trust it will serve as a rough measure of the activities of North American geologists. On this basis, the diagram clearly records a very rapid increase during the past decade in the ratio of publications dealing with applied geology to the total of geologic literature.

The figures show that applied geology was at its lowest ebb in 1890, when only 12 per cent, and at its highest flood in 1909, when 47 per cent of the total publications related to this subject. To consider the percentage of economic papers by decades: In the ten years ending in 1895 the average was 22 per cent; for the following decade, 30 per cent; and for the last five years, 44 per cent.

Another measure of this trend in geology has been obtained by a similar classification of the publications of the United States Geological Survey. The result of this enumeration is shown in a

second diagram (Fig. 2). In this, it will be seen that in 1890 less than 1 per cent of the publications issued by the federal survey treated of applied geology, and in 1910 the percentage was 98. Considering it by decades: For the ten years ending in 1895 the average of economic papers was 11 per cent of the total number of publications; in the following decade, 71 per cent; and in the last five years, 92 per cent.

These figures are not to be interpreted as evidence that pure science has not been recognized in these publications of the federal survey. I have classed with the applied geology group all publications which treat in any measure of this subject, though many of them deal chiefly with problems of more purely scientific interest. For example , the geologic folios, which include some of the most notable contributions to pure science, are here included in the literature of applied geology. To me it is less surprising that nearly all the recent publications contain some practical deductions than that most of those of twenty years ago omitted all data of this kind.

The marked tendency toward practical problems, as indicated by these figures, is by no means confined to one organization, for it is exhibited in the same degree by state surveys and is also reflected in the work of the universities. Nor is it limited to this continent, for countries as widely separated geographically and in scientific traditions as South America, Japan, and Germany show similar signs. Everywhere geologic research of practical problems is receiving more and more support, both publicly and privately.

It is pertinent to consider the attitude of the public at large toward this economic tendency. There are undoubtedly those who believe that the direction of scientific work should rest entirely with the investigator and not with the people. Let them bear in mind that geologic investigations, since they involve heavy expenditures and trespass on private property, can, for the most part be properly carried on only through government agencies, in this differing from such sciences as chemistry, physics, or biology, which can be furthered by private means. If geologic surveys are properly a function of the state, in the last analysis the people

must be the final arbiters as to what phase of the science is to be emphasized. In our democracy the citizen has a right to inquire what he, as a member of the body politic, is gaining by expenditures from the public purse.

It is estimated, on the best data available, that during the past quarter century the total grants for geologic work made by state and federal governments aggregate over eight million dollars. This may be regarded as evidence of public confidence. More significant to the present discussion is the annual grant of funds during this interval, and this is illustrated by a curve on the same diagram with those showing character of publications (Fig. 1). This curve is in part based on estimates, but these are without doubt sufficiently accurate to indicate that the total annual appropriations of state and federal governments for geology have been augmented at a rate which proves that they are affected by some other factor than that of increase of population. The annual grant of funds is now more than double that of twenty-five years ago. It is probably safe to interpret this as indicating that the present economic tendency in geology is approved by the people of the United States. The close parallelism between the lines marking the publications relating to applied geology and the annual allotments of public funds for geologic surveys is probably not entirely fortuitous.

Perhaps the best measure of popular confidence in the results of geologic research is the number of different geologic organizations supported by public funds. We are apt to credit the obtaining of government support for this or that research entirely to some individual or organization, forgetting that, until the general public has in a measure been persuaded of its value, all efforts would be useless. Therefore, when we find geologic surveys thruout the country supported by commonwealths having widely different social and industrial conditions, it is fair to presume that the average citizen has acquired the belief that these are attaining results beneficial to the community. The numerical increase of state geologic surveys during the last twenty-five years is illustrated by the curve on the diagram before you which marks the percentage of total number of states supporting geo-

logic work (Fig. 1). In 1886 24 per cent of the states had geologic surveys; in 1895 the percentage was 42, and in 1910, 80.

This growing public interest is also manifested by the increase in geologic teaching at colleges and universities. I interpret the statistics published by Prof. T. C. Hopkins as indicating that in 1886 there were about 220 of the higher institutions of learning in which geology was taught, while in 1894, there were 378. Of these, 51 had geology organized as a separate department. I have been unable to find any more recent data on geologic education, but that it has made great strides in the last seventeen years will be conceded by all. It will also be generally admitted that the teaching of economic geology is receiving constantly greater attention in the colleges and technical schools. More significant evidence of the present status of geology among the people is the fact of the large number of geologists now in private employment. There are many professional geologists who are engaged in consulting practice. Nearly every large mining company and many railways include in their personnel one or more geologists. In a commercial directory of mining experts recently published fully 10 per cent classed themselves as geologists, while an edition of the same directory issued ten years ago included only one who claimed to be a geologist. While at that time, as now, many mining engineers were in fact professional geologists, they did not care to advertise the fact.

All this indicates that applied geology has during the last two decades become a dominating element in our geologic work; also that this tendency toward industrial problems pervades all geologic investigations, whether under federal, state, or private auspices. Furthermore it has been made evident that this trend is not limited to the North American continent, but is world-wide. It is clear, also, that since emphasis has been laid upon the economic side there has been a marked increase in the support given to geologic work, from which fact may be drawn the logical conclusion that the public endorses this policy. It does not necessarily follow that this dominating practical note in geology has made for the advancement of the science. Before discussing this important question it will be well to trace briefly the origin of geology as an applied science.

It seems to be generally assumed that the application of geology to industry was not attempted until after its development into a more or less complete rational science. It can not be denied that the application of the principles of a science must await the establishment of those principles through scientific inquiries. It is true, however, that long before geology had developed as a science men observed the geologic phenomena that bore on certain vocations and often correctly interpreted such observations.

The science of applied geology, therefore, had its origin among those who, like the miners, were by vocation brought into intimate contact with natural phenomena. Many of the elementary facts relating to mineral deposits were forced on the attention of the miner, and as the correct interpretation of these facts added to his material welfare, some deductive reasoning was undoubtedly applied. The rudimentary conceptions thus formed were more likely to be correct than those of the early closest academician, whose science for generations began and ended in pure speculation.

Therefore, to trace the origin of applied geology the oldest archives treating of mining, quarrying, agriculture, engineering, and mineralogy must be searched—a task which has been quite beyond me. And reaching far back of any written record was the traditional lore bearing on geologic phenomena of countless generations of miners and husbandmen. Even the man of the stone age must have subconsciously acquired knowledge of the distribution of the materials which he fashioned into implements of the chase and war. If we are to allow our imagination full scope, we can conceive of some primitive economic geologist who, by finding a deposit of copper and revealing the superiority of the new material for weapons, became the hero of his tribe.

While our Aryan ancestors appear to have been ignorant of the use of metals when they first invaded the Mediterranean countries, yet they acquired a knowledge of them from the Semitic races long before the dawn of history. In winning these metals primitive man used methods which required neither any high degree of technical skill nor a knowledge of the form of their occurrence. Mining, being second only to agriculture in its

importance to the human race, became more systematized with the progress of civilization. By the time historical records began the recovery of metals and the quarrying of building stones were well-developed arts, and there is no reason to suppose that the mode of occurrence of the deposits exploited were ignored by those whose livelihood was involved.

The rulers of this early period, keenly alive to the value of the metals, undoubtedly caused this source of wealth and power to be investigated by able men. It is recorded that Philip of Macedon evinced his interest in mining by examining in person some underground workings in Thrace. Jason's search for the golden fleece pictures the prospector of those days as a national hero. In any event, it is certain that millions of ounces of gold and silver and many tons of copper, as well as tin and iron, had been produced centuries before the Christian era. We must believe that this production indicates a sufficiently developed industry to employ not only skilled artisans but also those who delved deeper into the problems of mining. The ancient Egyptians were eminently practical and developed a high degree of skill in certain branches of engineering. Undoubtedly the Egyptian engineers paid some heed to the distribution of building stones as well as to methods of quarrying, while among other peoples who excelled in metal mining it is presumed there were engineers who specialized in mining matters, as do their successors of today.

It is far easier to speculate on the knowledge the ancients may have had of some of the principles of applied geology than to trace the actual extent of this knowledge. Ancient Hebrew literature abounds in references to the metals and their utilization, but furnishes little clew as to what was known of them. The same is true of the records of ancient Egypt, in which both placer and lode gold are mentioned. One document that has come down to us shows that location of mineral wealth was considered worthy of note. An ancient papyrus, dating about 1350 B.C., displays a crude map for the purpose of locating Nubian gold mines. It is one of the oldest maps in existence and the first which can be said to impart geologic information. The oldest written record of geology or allied subjects is Theophrastus' descriptions of

metals, stones, and earths, dating back to 315 B.C. Pliny's work of four centuries later seems to have been the first attempt at a complete treatise on minerals of economic importance, but he was more concerned in the utilization of the metals than in their mode of occurrence. Other of the ancient writers, notably Aristotle, touched on geologic subjects, but rather from the standpoint of speculative philosophy than of interest in material problems. Some of the early geographers and historians, like Strabo and Herodotus, discussed the geographical distribution or the exploittation of metals. Another field of applied geology is found in treatises on agriculture containing references to character and distribution of soils. Even Virgil in his Bucolics attempts a practical classification of soils. As this dwells on the physical rather than the chemical properties of soil, it would seem to have at least the merit of being in accord with some of the latest scientific maxims.

I have dealt with this subject as if the nations of Europe and western Asia had alone made advances in technology. Mining and metallurgy, even in very early times, were important industries in both India and China, and it is not unlikely that there may be in those countries a literature of practical geology which antedates our own.

The meager records of the early period of mining give no clew to the knowledge of applied geology held by the ancients. But that they were not entirely ignorant of its principles is to be presumed from the importance of the mining industry, and the absence of written records does not argue against this theory. The same is true of other arts. We do not assume, for example, that the principles of mechanics applied to structures were not understood because there were no written treatises on architecture until centuries after many periods of architecture had successively developed and declined.

Scant as is the literature of mineralogy and mining up to the early part of the Christian era, the succeeding ten or twelve centuries are almost entirely without records. This was the medieval period of intellectual stagnation—the eclipse of scientific and critical thought. The Arabs, who alone preserved the traditions

of antiquity during this lapse, made considerable contributions to scientific knowledge, not neglecting mineralogy. Aside from this, there are only a few minor references to the subject in the chronicles of that time.

While science was neglected in the middle ages, the arts continued to progress, and among these mining was important. It is recorded that in Charlemagne's time thousands of miners were employed in the metal industry of northern Tyrol, and many other countries made notable contributions to the metallic wealth of the world. Coal mining began in England and Germany in the twelfth century. In fact, the mining industry assumed an importance which attests a high degree of administrative and technical skill.

With the revival of learning in the fourteenth and fifteenth centuries, scholars began again to turn their attention to the natural sciences. At first they labored solely to verify and amplify the theories of the ancient writers, never doubting that the classical philosophers had encompassed the entire realm of human thought. Generations of scholars sought their science in the Greek and Roman literature. But with the renaissance scholastic thought was freed, and then the first epoch of scientific geology began.

The wide chasm which separated the academician from the technician at that time prevented any utilization of the great store of geologic facts accumulated by miners. The miner had neither education nor incentive to record the facts so laboriously collected; the scholar had yet to realize that nature must be studied by observation and deduction, not by speculation alone. The cosmogonist wrote his treatises on the origin of the world with his vision limited by academic walls, while the miner held his knowledge as important only for his need.

Agricola was one of the first scholars to consider the practical problems of the miner. His works, published in the middle of the sixteenth century, show both keen observation and realization of the importance of applied geology. The German mining industry had at that time advanced sufficiently to have a large technical vocabulary of its own. But as Agricola wrote in Latin, he

was forced to translate these technical terms as best he could. German mining methods and terminology must then have found wide acceptance in Europe, for Pierre Belon, the French naturalist recorded that in 1546 they were in use in the Thracian gold fields—then as now a part of the Ottoman Empire.

In Agricola's day there appeared a number of other treatises dealing with some phase of applied geology. These were mostly devoted to mineralogy, which was destined to become a science long before geology had passed beyond the speculative stage. Most of this early literature was in Latin and therefore calculated to have little influence on mining practice. It did, however, bring the scholar into closer touch with the phenomena of nature and thus pave the way for a rational science of geology.

In the early history of the science pure and applied geology can be compared with two confluent rivers having widely separated sources—the one springing from the high realm of speculative philosophy, the other having a more lowly subterranean origin. These two streams of thought gradually drew together, for a space flowing side by side, and finally merged into one great stream.

The following passage, written by Peter Martyr, in 1516, while describing the golden wealth of Hispaniola, reflects something of the status of geology in his day:

> They have found by experience that the Vein of gold is a living tree, and that the same by all ways spreadeth and springeth from the root, by the soft pores and passages of the Earth, putteth forth branches, even to the uppermost part of the Earth; and ceaseth not until it discover itself unto the open air; at which time it sheweth forth certain beautiful colours in the stead of flowers, round stones of golden Earth in the stead of fruits, and thin plates in stead of leaves. . . . . For they think such grains are not engendered where they are gathered, especially on the dry land, but otherwise in the Rivers. They say that the root of the golden Tree extendeth to the center of the Earth, and there taketh nourishment of increase: for the deeper that they dig, they find the trunks thereof to be so much the greater, as far as they may follow it, for abundance of water springing in the Mountains.

This fantastic account of gold deposits contains a sufficient kernel of truth to indicate that the writer had at least some comprehension of the form of auriferous veins and their relation to gold placers.

One of the earliest recorded attempts of a practical application of geology is that of George Owen, a country squire of Wales, who about 1600 prepared a lengthy description of Pembrokeshire in which he discussed the occurrence of limestones and coal. He appears to have been the first to note the change of bituminous coal to anthracite. Owen's practical purpose is made clear by the following quotation from his writing:

> . . . . it may be a guide to some parties to seek the lymestone where it yet lieth hidden and may save labours to others in seeking it where there is no possibility to find it.

While men of the Agricola type were assembling and classifying observations on minerals and ore bodies, another group of scientists was engaged in wordy wars about such problems as to whether fossils had been formed by the influence of stars or were the remnants of former living organisms. It is noteworthy that among the most rational contributions to this discussion, which continued over a century, were those of Leonardo da Vinci and Nicholas Steno, the first of whom based his arguments on his own observations as an engineer, while the second had some practical experience in the study of ore bodies. These two belonged to the class of scientists designated by John Webster in his *History of Metals*, published in 1671, as "experimental observers," of whom he says:

> For either they were such as attended the mines, or went thither to converse with the workmen to inform themselves, or bore some office about those places, or were those that either for curiosities sake, or to enrich their knowledge, did gather together all the minerals they could, or used the most of all these ways to gain understanding. And therefore I commend these above all the rest before named, to be read and studied of all officers and men belonging to any mineral or metallick works; and of all young students and beginners that seek after mineral knowledge: because these authors speak not altogether by opinion, fancie, and conjecture; but forth of their own experience, and the experience of those that were conversant about the mines, and getting of ore, and purifying and refining of them; and therefore more certain to be relyed upon for leaders and teachers. And more, because they have written what they knew, openly and plainly as the subject would bear; and not in parables, and ænigmatical expressions.

This treatise contains, amid much that now appears childish, some practical hints for the discovery of ore bodies. Webster

laments the almost universal ignorance of this subject, which he accounts for as follows:

> That the way and means to discover the nature of minerals, is not onely difficult and dangerous, but in itself is so sordid, base and troublesome, that the most men of parts, will hardly adventure themselves into the pits or shafts where ores are usually gotten; nor can indure to stay so long, that they can rightly inform themselves of anything that may be satisfactory to their inquiries. And the Miners or Workmen (for the most part) being but people of the most indigent sort, and such as whose knowledge and aims reach no higher than to get a poor living by that slavish labour, regard to inform themselves of no more then what may conduce to such a poor and servile kind of living; by which means they are little able to give any learned man satisfaction to those necessary inquiries that might tend to enable him to judge rightly of the nature of the things in that subterraneous kingdom.

The prejudice of the scholar against learning from the miner, so quaintly described by Webster, gradually died out in the eighteenth century. Thereby the science profited much, through acquiring a better ground-work of fact, while, on the other hand, technology derived assistance from applied science. Even before Werner's day a number of mining officials discussed in print the occurrence of mineral deposits. As a result of this better understanding between the scientist and the practical man geology developed from a condition of pure speculation into a science which approached the rational and concrete. It need hardly be added that the advances made in chemistry, physics, and biology, were essential to this progress.

By the latter part of the eighteenth century conceptions of stratigraphy began to take definite form. In this field, again, the miner to a certain extent forestalled the scholar, for he had recognized that locally, at least, the earth crust was built up of superimposed strata having a definite order. He had also noted that this order was sometimes interrrupted by breaks and in the underground workings had opportunity to grasp some details of tectonic geology.

The advancement of science and arts toward the end of the eighteenth century had been such as to create a demand for trained engineers. In the field of technical education mining was given the first recognition, for the school at Freiberg was established in

1765, twenty years before the existence of any other school of engineering, except those devoted to military science. This school was to have a world-wide effect on geology, through the influence of Werner, the first great teacher of the science. The founding of other mining schools followed rapidly, indicating a need throughout continental Europe for trained mining engineers. With the exception of Freiberg none of these schools gave special heed to science, but their establishment was of great importance to applied geology, as it gave definite recognition to the fact that mining was to be directed by engineers and not by artisans. The advent of the trained mining engineer was of first importance, for on him was to fall much of the work of advancing the new science.

On the continent mining was chiefly carried on by or under the direct supervision of the state, and the need of properly trained engineers was probably the chief reason why technical mining education began before other branches of engineering. In England, on the other hand, mining was mostly a matter of private enterprise, and technical education lagged far behind the continent. The men entrusted with the direction of mining affairs seem to have been drawn from the practical school of experience and were known as mineral surveyors. To this class belonged William Smith, the founder of stratigraphic geology.

Worthy of note also is John Williams, a mineral surveyor, who preceded Smith by one generation. Williams was a Welshman, who was bred as a miner, served as a soldier under the Dutch flag, and held various responsible positions in the coal and lead-mining industries. In 1789 he published a Natural History of the Mineral Kingdom, which is remarkable for expressing some of the modern views on applied geology. It contain a large number of accurate observations, notably on coal and lead deposits. In discussing ore deposits Williams suggests a probable genetic relation between intrusive dikes and mineral veins. Unfortunately for Williams' standing as a scientist, he considered it necessary to present a theory accounting for all geologic phenomena and to show the errors in Hutton's conclusions, which had then just appeared.

Inasmuch as Williams treated coal deposits quantitatively he was far ahead of his generation. He pointed out that coal beds

are definitely limited, and this at about the time that Werner was preparing to launch his theory of "Universal formations." A few quotations from his book will serve to illustrate Williams' attitude:

> The result of his investigation refutes by inference another erroneous opinion concerning coal, which I have often heard asserted with great confidence, viz., that coal is inexhaustible. That the fund of coal treasured up in the superfices of the globe, for the accommodation of society, is very great, I readily acknowledge; but that it is inexhaustible, in the proper sense of the word, I deny.
>
> If our coals really are not inexhaustible, the rapid and lavish consumpt of them calls aloud for the attention of the Legislature, because the very existence of the metropolis depends upon the continued abundance of this precious fossil, and not only the metropolis, but also the existence of the other cities and great towns, and of the most fertile countries in the three kingdoms. depend upon the abundance of this valuable article; and moreover, most of our valuable manufactures are in the same predicament, and, therefore, if our coal mines are not inexhaustible, it is high time to look into the real state of our collieries.
>
> I feel in myself a strong reluctance against sounding the alarm to my country in a matter of so much importance. I am but an obscure individual of very little consequence in the world, and I have not the least doubt that I shall be severely censured by many for my presumption, and therefore I proceed with sensible remorse; but it is not guilty remorse; on the contrary, my heart tells me, that were I to temporize with my own feelings of reluctance, and to conceal a truth which so nearly concerns the welfare of the community, for fear of incurring censure, my silence would be unpardonable.
>
> The present rage for exporting coals to other nations may aptly be compared to a careless spendthrift, who wastes all in his youth, and then heavily drags on a wretched life to miserable old age, and leaves nothing for his heirs.

While Williams' dire prophesies, made a century and quarter ago, of the early exhaustion of England's coal have not been justified, yet he seems to have been one of the first to urge upon public attention the close relation between the prosperity of a nation and its fuel supply. He was also a pioneer in recommending governmental surveys and investigations of mineral resources. After pointing out the value of the Cape Breton and other coals in the British North American possessions and recommending their development, he goes on to say:

In discussing this topic, we presume to suggest, that, in the first place, it is necessary for Government to explore and discover these coals, and lay them bare for the inspection of British coal masters or companies, and with this view, the first thing to be done, is to employ a prudent man of abilities and skill in the theory and practice of the coal business; to survey the West India coals and coal fields; to make such trials upon the coals already discovered, and those he may discover, as may be necessary to ascertain the thickness, quality, and situation of each stratum of coal that may be judged worth attention; and to make out a full and substantial report of all the material circumstances relating to each coal, for the information and use of Government, and of such gentlemen and companies as may wish to look into this interesting subject.

These recommendations for governmental surveys of mineral resources were made a generation before they were followed and fully a half century before the nations of the world were generally to accept the principle. Williams also touches on some of the problems which absorb us today. After advocating the investigation of the colonial coal fields, he says, in words which have a familiar ring:

When this report is made and considered by Government, suitable encouragement should be offered to gentlemen and to companies of character, stock, and abilities for such undertakings, to open and work some of these coals. . . . .

The first undertakers should be allowed a sufficiently extensive coalfield, and every reasonable privilege and indulgence; but they should not have a monopoly. Other adventurers should have room to employ their skill and capitals in this line of business in the west as well as in Britain. Monopolies seldom do much good. The views of monopolists are always too selfish and confined to be of extensive utility and public benefit.

While Williams was among the first to recommend governmental mineral surveys, the idea of showing mineral deposits on maps appears to have been part of a plan for soil maps conceived by Martin Lister a century before, and put into practice by Guettard in 1746. Sir Archibald Geikie has credited the first geologic map to this eminent French naturalist, but has not sufficiently emphasized the fact that Guettard's map also showed the distribution of mines and mineral deposits. Others followed his example, and before the close of the eighteenth century the cartographic representation of geology and mineral deposits had become well established.

The nineteenth century opened during the epoch of intellectual freedom which followed the turmoil of the French Revolution. The time was favorable to the progress of science. The scholar felt free to follow scientific inquiries to their logical conclusions untrammeled by the interdict of authority. Nowhere was this more true than in the field of geology, for, notwithstanding the efforts of dogmatic theology for upwards of half a century to dominate geologic thought, its edicts could hamper the growth of the science but little.

Further incentive sprang from the development of new political ideals. As the nation began to concern itself with the needs of the individual citizen the application of science to human needs was encouraged. Under the old regime, so long as the wants of the ruling classes were supplied no thought was given to the wants of the masses. When this attitude was changed it was natural to seek the aid of the scientist in ameliorating conditions. Therefore, the dawn of the new century was propitious not only to the advancement of pure science, but also to a general appreciation of applied science.

Nowhere were conditions for the evolution of geologic science better than in our own land. Being far removed from the controversies which occupied the sole attention of many European geologists we could accept or reject without prejudice this or that theory. Our people had entered upon the exploitation of a new land, with boundless possibilities of natural wealth, and pioneer conditions brought most of them into intimate contact with natural phenomenon. Books of travel written in the early part of the century bear witness that a close observation of geologic facts was forced upon every traveller.

A general interest in science and its application was prevalent in America, even in colonial times. This was reflected in the scientific and practical character of educational ideals. In its first advertisement, issued in 1754, Columbia College (then called King's) provided for the instruction of youths—

"in the arts of numbering and measuring; of surveying and navigation; of geography and history; of husbandry, commerce, and government, and in the knowledge of all nature in the heavens above us and in the air, water, and earth around us, and in the various kinds of meteors, stones,

mines, and minerals, plants and animals, and everything useful for the comfort, the convenience and elegance of life; and in the chief manufactures of these things."

This was half a century before the idea of scientific and technical instruction had taken root in European countries. In the period extending from 1768 to 1811 chairs of chemistry were established in eleven colleges of the United States. In 1824 the Rensselaer Polytechnic Institute was founded—the first school of applied science in any English-speaking country. The avowed aim of this school was to apply "sciences to the common purposes of life." Van Rensselaer, who founded it, was a patron of geologic science, and Eaton, the geologist, its first president.

Geology had, however, received recognition in several American colleges long before the founding of the Rensselaer Institute. According to Professor Hopkins there were 31 American colleges which offered courses in geology previous to 1845. Of these, one began teaching geology in 1804, one in 1807, one in 1819, and one in each of the years from 1820 to 1845. The large number of scientific societies founded at this time shows the widespread interest of the people in science. Nearly every town had its lyceum of natural history, while the larger cities boasted of academies of science and similar associations, of which several have survived to the present day. In 1819 the American Geological Society was organized—only twelve years after the founding of the Geological Society of London and nearly thirty years before that of the Deutsch Geologische Gesellschaft.

Numerous journals devoted to science and art were established during the period under discussion. While some of these were only short lived they attest the interest in science of the American people. Another example of this interest is found in the course of lectures on natural history which, according to Dr. Merrill were delivered before the New York State Legislature by Amos Eaton in 1818. This is probably the only instance in our history where a body of law makers have welcomed serious instruction in scientific matters.

Most of the collegiate instruction and the scientific societies had for their purpose the promoting of knowledge in pure rather

than applied geology, but it was in the latter that geology really had the support of the American people. One far-reaching influence on the development of applied geology in the early part of the last century was the scarcity of mining engineers or experienced operators, while the vocation of prospecting was almost non-existent. Our mining industry was in the early stages and there were almost no engineers and but few so-called practical men to whom the people could turn for information. In European countries, on the other hand, centuries of mining had developed a class of professional men other than geologists who were considered authorities on mineral wealth. But in our own country it was the scientist rather than the engineer or the practical miner who was called upon for information. This not only led to the utilization of science in the preliminary work of seeking mineral deposits, but also had the effect of forcing the scientists to give their investigations a practical turn.

Either from choice or necessity, the early American geologists, like their successors of today, always emphasized in their work the needs of the community. McClure devoted much of the brief text which accompanied his geologic map of the eastern United States to the relation of geology to agriculture. Eaton's first work bore on the resources of the region adjacent to the Erie Canal. Rodgers elucidated the structure of the coal fields, while Jackson attempted a classification of the public lands of the State of Maine.

I venture the opinion that one reason why the investigators of this continent have accomplished so much for the advancement of geology is that their research has never been entirely divorced from the field of applied science. We have had no distinct schools of pure and applied geology, as there were until recently in other lands. In Europe there was the practical school of the miner, whose scientific conception seldom reached beyond his immediate environment; and there was the school of the scholar, whose angle of vision was apt to be too wide to focus on facts near at hand. There were, indeed, some exceptions, for the scholar Agricola learned from the miner; Werner's teaching was, in theory at least, an application of geology to the mineral industry; and

William Smith used his knowledge of stratigraphy in the practice of his engineering profession. Even in Europe the distinction between the work of these two schools has now almost disappeared.

The general interest and faith in science during the early history of our country is well exemplified in the attitude of public men. Our first two presidents, in spite of the fact that they differed greatly in temperament and experience, showed more interest in scientific work than almost any of their successors. Washington's training as an explorer, surveyor, and planter and his close connection with the beginnings of the iron industry is perhaps sufficient to account for his attitude toward science. He is probably the only president who, by his own efforts, attempted to advance applied science. While president he started an investigation of the soils of the eastern states through personal correspondence. More important, however, was the work of Jefferson, in bringing about the establishment of the chair of chemistry at the University of Virginia, thereby introducing scientific teaching into this country. He also discussed the mineral resources of Virginia in his book on that commonwealth, wrote, while vice-president, geologic paper, and above all inaugurated that system of exploration and investigation of the trans-Mississippian region which was to yield such fruitful results in the century to follow. John Adams, while he took no personal part in promoting scientific research, manifested interest in it by helping to establish the American Academy of Arts and Sciences.

A review of the conditions which brought about the rapid growth of geologic work in this country during the first decades of the nineteenth century cannot fail to consider the political and industrial situation. The war of 1812 had united as one nation the commonwealths which up to that time, in spite of the federation, had strong centrifugal tendencies. Duing the war with Great Britain New England had been on the verge of rebellion, while the Trans-Appalachian region was not held to the East by any strong bonds. The country, rent by domestic quarrels and the turmoil of opposing political factions, paid small heed to the problems of industry and commerce.

After the war the people thought less about state rights and more about industrial prosperity. There was no longer a French party or an English party, but men of all political faiths had come to the conclusion that we must work out our own salvation. We had learned to supply our own material needs during the war when English frigates, cut off European sources of supply. In short, the nation had found itself and was ready to begin to harvest the resources of the vast territory which the war had settled for all time was to be our own. Our people, while possessing the self-confidence of the pioneer, were facing new problems, and, guided by their scientific instincts, turned to the scientist for help.

In spite of the fact that the war had developed a relatively strongly-centralized federal government, yet our political theory

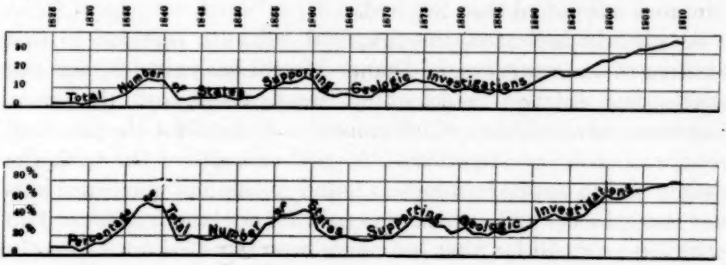
Total Number of States Supporting Geologic Investigations
Percentage of Total Number of States Supporting Geologic Investigations

Fig. 3. Total number and percentage of total number of states supporting geologic work, 1825 to 1910

was still one of state rights. Moreover, the Republicans were in power, with a hopelessly small Federalist minority. It was natural, therefore, that the people, loyal to their political faith, should turn to the commonwealths for aid in developing the new land. This aid for the most part took the form of large grants for public improvement of transportation facilities—at first for canals and wagon roads, later for railways. During the period ending with 1838 the states borrowed sums aggregating over $160,000,000 for purposes of public improvement. Compared with this sum, the expenditures for geologic surveys were small. It is a significant fact, however, that in 1838, a larger percentage of the states supported geologic surveys than in any subsequent year until 1898. This is graphically illustrated in Fig. 3. The upper

curve shows the total number of states, and the lower the percentage of total number which supported geologic surveys between 1826 and 1910.

The very rapid increase in state surveys is all the more significant when compared with the status of governmental surveys in Europe. Though much geologic work was done in European countries during the early part of the century, it was not until about the middle, that the governments began organizing systematic surveys. England led by establishing her survey in 1832. Next came surveys of Austria-Hungary and Spain, organized in 1849, of Bavaria in 1851, and France in 1855. Most European countries did not undertake systematic geologic surveys until about 1860, or more than twenty years after our first maxima of state surveys had been reached.

As already indicated, the principal influence that led to this first era of state surveys, as Doctor Merrill has called it, was the wide-spread interest in scientific investigations and the great industrial advancement which created a demand for the practical results of such investigations. A good example of the faith the people had in applied geology is found in the first geological survey made in Georgia, which was paid for by land owners of two counties—a condition that has never been repeated until recently in some of the rich mining districts of the west.

Another reason for the large number of state grants for geologic work lay in the general westward movement of population from the Atlantic states. This had a two-fold effect on geologic surveys. First it gave rise to a demand for information about the new lands, and second, it put the older states on their mettle to hold their population. So rapid was the westward movement that the Atlantic states became alarmed for their future. In 1815 and 1816 the legislatures of both North Carolina and Virginia appointed committees to divise means for checking the drain on their population. This was unquestionably the motive in establishing many of the eastern state surveys, and in directing their activities toward agricultural problems.

Meanwhile the federal government had undertaken the investigation of the resources of the unorganized western Territories.

The chief purpose seems to have been a classification of the public lands—a work which was to be interrupted for over half a century and then resumed as the proper function of federal geologists.

According to Doctor Merrill[2] the first epoch of state surveys declined even more rapidly than it arose, due, largely to the financial crisis of 1837. An era of promotion, inflation, and straining of state credits to their uttermost, accompanied by a waste of the borrowed millions and the lack of any sound federal financial policy, resulted in a money panic, the collapse of many ill-advised enterprises, the repudiation of their public debts by several of the states, and a wide-spread commercial depression. It is no wonder that, under these conditions, geologic surveys were regarded as luxuries that might well be spared; particularly since these first governmental surveys, it must be admitted, hardly justified themselves from the standpoint of practical results. This fact does not detract from the credit due the pioneer geologists who carried on these surveys under almost insuperable difficulties. They learned much about real distribution of the larger geologic units, but most of the investigations were not detailed enough to yield results of practical value. Moreover, even in that day many geologists were still living in "flat land"—they considered formations in only the two horizontal dimensions; for while the vertical element was by no means ignored, it was not closely understood.

During the decade following the panic, few states had surveys and no great progress was made in the science, beyond the publication of results attained in the previous era. Though the contributions to geologic literature by the class of professional geologists—whose appearance was perhaps the most important result of the activity of the previous decade—were not unimportant, yet as a whole both pure and applied science were at a rather low ebb.

The panic was but a temporary check to the industries, however. The estimated production of pig iron was 347,000 tons in 1840, and 600,000 in 1850, while the coal production during the

[2] The extensive use I have made of *"Contributions to the History of American Geology"* by G. P. MERRILL will be evident to all who have read that work.

same period increased from 2,000,000 to 7,000,000 tons, and the railway mileage from 2818 to 9021. These industrial advancements were accompanied by the rapid settlement of the middle west, by the beginnings of copper mining in Michigan in 1844, and of iron mining in Michigan and Missouri in 1853, and most important of all, the discovery of gold in California in 1848. All this activity gave a new impetus to geologic work, which is reflected in the revival of interest in state surveys. At this time, too, men began to dream of a trans-continental railway and therefore the federal government undertook a more systematic exploration of the western cordilleran region than had previously been made. The curve of state surveys, as seen in the diagram, continued to rise until the outbreak of the civil war. In this second epoch of geologic work the states of the middle west—then the frontier—led. This was but natural, because history has proved geology always appealed more strongly to the pioneer than to any other class of people.

It is difficult to measure the accomplishment of this second period of geologic activity under state and federal auspices, owing to its abrupt termination by the civil war, which interrupted many important investigations. One fact stands out clearly: that applied geology was the mainspring of most of the research, and the results indicate that pure science had not been the loser thereby.

The prosperous time following the civil war in the north and west, with its almost unique industrial advancement, again centered public interest on mineral resources. This caused the federal government to resume explorations in the west, which took the form of areal geologic surveys and in some cases detailed study of mineral deposits. Many states undertook similar work, and the curve of geologic surveys arose until the interruption by the panic of 1873.

The results thus attained proved a final justification of geology, not only as an intellectual pursuit, but also as a practical aid to mankind. While the immediate benefits of these investigations were large, they were not so important as the institution of geologic mapping, based on accurate mensuration. Crude as those

maps were compared with the present standards of refinement, they represent the earliest general attempt in this country to apply engineering methods to geologic problems. It was very unfortunate that this first epoch of engineering geology, as it might be called, was so soon interrupted and the work practically discontinued for over a decade. The people were, in fact, hardly educated up to an appreciation of its value; moreover, the natural resources that could be readily exploited without the aid of science were so extensive that the time was hardly ripe to make full use of this new geology.

We have seen that the period following the civil war was especially favorable to the development of applied geology. The same is true of pure science. This, in fact, has been the history of geology in this country—advances in pure science were always in more or less direct proportion to advances made in the applied science.

It has been shown that, in the early history of the nation, the genius of the American people was essentially scientific. A deep interest was felt both in the facts and deductions of science, and in the affairs of life deference was paid to the opinion of the investigator. Unfortunately, for reasons which are difficult to fathom, this scientific attitude gradually declined. At the beginning of our national existence we were in close contact with the intellectual life of Europe, which was then essentially scientific. This gave us our first intellectual stimulus and led us to do our full share of the work of advancing both pure and applied science. Then came an interim between the time when we forsook the intellectual standards of the old world and before we fully established those of our own. Meanwhile, the opening of a continent, with its unbounded resources, was calculated to bring out the characteristic efficiency and self-reliance of the average American. Then gradually developed what may be called the era of the "practical man"—an era characterized essentially by unscientific thought among the mass of the people. The "practical man" now became a national fetish, and the people, overlooking the fact that his success was due to energy and opportunity, attributed it rather to the absence of technical and scientific knowledge.

Nowhere was this national trait better shown than in the mineral industry, where the era of the "practical man" cost the nation untold millions. His distrust of applied science was deep-rooted. For a generation every mining community swarmed with these self-styled experts, whose technical and scientific limitations were only exceeded by their blatant self-assertion.

Unfortunately, at this time there also developed between the geologist and the mining engineer an antagonism, which was detrimental to the advance of the science. A school of geology arose which revived to a certain extent the ancient practice of speculation without observation and regarded itself as moving in a higher intellectual sphere than that of the engineer, who dealt with practical problems. On the other hand, many engineers came to regard all work of the geologist as either visionary or purely speculative.

Since the rise of the modern school of applied geology, which may be said to have begun in the eighties, this antagonism between the engineer and the geologist has gradually disappeared. The geologist has made his results of more value by adopting some of the methods of the engineer, while the engineer no longer hesitates to use geology in his own field. Both professions have been improved by this mutual help, and the geologist has by no means gained the least. The modern mining engineer now recognizes that, even in his own special field, scientific investigations are essential. This is evidenced by the general hearty support given by engineers to the new federal Bureau of Mines.

It is not necessary to describe in detail the recent progress in applied geology. While most of the countries of the world have taken part, it is a field that the American geologist has made peculiarly his own. Among our important contributions in this field is the geology of mineral oils, presented by Mr. Campbell to this Society last year. In this, as in the survey of coal deposits, stratigraphic and structural geology have almost come to be exact sciences. Equally important to the nation are the results achieved in underground water investigations. The tectonics of mineral veins now also approaches an exact science; while many of the conclusions on the genesis of ore bodies, notably that

of secondary enrichment, are among the triumphs of applied geology.

Moreover, the field is being extended. In Germany the work of the geologist is regarded almost as essential to railway or canal location as that of the engineer—a lesson we have only recently learned at Panama. The investigations of soils is now a distinct science, based largely on applied geology. Questions of public health, such as purity of water and sanitation problems, also in part fall in the domain of the geologist.

A significant phase of the new epoch in applied geology is its contributions to political economy. A striking example of this is the geologic survey of Korea, executed by the Japanese during their war with Russia. It need hardly be said that this was not made for the purpose of advancing geologic knowledge, but solely to gain a scientific valuation of the land which was costing so much blood and treasure. Though the present status of the science does not permit of a quantitative determination of resources which is more than approximate, yet the fact that geologists are being called upon by political economists for assistance indicates how fundamentally the science affects the welfare of the nation.

This historical survey of applied geology, in which special emphasis has been laid on its progress in this country, seems to point to several conclusions. First, that much of the modern science of geology originated in the field of applied science. It was the striving of mankind to solve problems of material welfare that gave the first impulse to geologic thought. Second, that, as a rule, the science has made most rapid strides at those times when its study was inspired by a desire to achieve some practical end. Whenever geology has become entirely divorced from industry, it has drifted towards pure speculation. The geologists of the past, like those of the present, received much of their inspiration from the fact that they were adding to the material welfare of mankind. Werner, Humboldt, von Buch, de la Beche, were not only trained as mining engineers, but continued for most of their careers to be intimately connected with the mining industry. William Smith was an engineer before he was a geologist, and even Hutton knew

from personal experience the value of applying the sciences of agriculture and chemistry. On this continent McClure, Eaton, Rodgers, Owen, Leslie, Logan, Whitney, Orton, Cook, Dawson, and King, with a host of others, were all identified with the industrial application of their science. The elder Silliman, in an account of his own training in geology, said: "I learned in the mining districts how and what to observe." The years that Dana spent on explorations may be counted in the field of applied geology. James Hall, for two generations the leader in American geology and the founder of that organization which for three-quarters of a century has preserved the highest scientific ideals, gained his early inspiration in studying practical problems. An enumeration of the leading geologists of the present generation will, I think, show that the larger part have given much attention to the material application of geology.

The recent economic trend of geology is only a counterpart of similar tendencies in most fields of scientific research. The introduction of science into practical affairs is a feature of the present age. It has come about not only because, as the sciences progressed, their results were more directly applicable to material problems, but more specially because of the gradually changing conditions throughout the world. With a sparse population and abundance of natural resources the need of applied science is never so evident as when the lands become crowded and the more readily accessible resources depleted. The people of a virgin land need pay small heed to exhaustion of soil or destruction of forests, and can carry on shallow mining operations with little recourse to science or technology. It is only when increasing population results in a demand for a greater food supply and makes sanitation important; when the depletion of timber becomes a factor in cost of structures; and the superficial deposits can no longer yield sufficient minerals, that the need of scientific knowledge becomes strongly emphasized. This stage has been reached in most of the civilized countries of the world to a greater or less extent, and the evils of relative over-population and depletion of nature's wealth are resulting in an appeal to applied science. China stands alone among the great nations of the world in not utilizing scientific

thought to better the conditions of her people. The present turmoil in China can probably be interpreted, in the last analysis as a protest against the affairs of state being guided by the classicist rather than by the scientist.

While we may criticise China for not accepting the dictum of science, we have only recently departed from a similar attitude, though our abundant resources have made our own faults less conspicuous. In this respect the present generation has made greater strides than all that preceded. We are now applying science to the affairs of the nation as never before. The old-fashioned publicist, with his classical education or, at least, traditions, is being shouldered out of the way by the man who analyzes the problems of public welfare on scientific principles. The trained investigator is being more and more appealed to in the affairs of the nation. In this we are following Germany, whose long leadership in pure science has now been overshadowed by her leadership in applied science. We have begun to realize, that it is one thing to win prosperity and happiness out of the bounty of a new land, another to gain it by utilizing resources which can only be made available by scientific genius.

Mr. Gilbert has said that "pure science is fundamentally the creature and servant of the material needs of mankind." Yet it is not uncommon to find the devotee of pure science assuming that his field is on a higher plane than that of those studying problems which involve the material welfare of the human race. This seems specially true in the field of geology. If a bacteriologist finds a new toxin for a disease germ, a botanist a new food plant, a sanitary engineer a measure for preserving human life, all unite in commending his work. Yet there are not a few geologists, though I believe a constantly decreasing number, who seem to view with suspicion any attempt to make the science of geology more useful. Those who are devoting themselves to economic geology are charged with commercializing the science, as if the applying of its principles to better the conditions of the people were not the highest use to which scientific research could be put. One reason for this attitude is because much which has been masquerading as applied geology is not science at all. The commer-

cial exploitation of natural resources under the cloak of geology is not to be confounded with geologic research, which has for its aims the application of scientific principles to the needs of man.

The geologist who is studying the resources of the public domain to the end that a sound policy may be adopted for their utilization, or he who is gaging the exhaustion of our mineral wealth by studying statistics of production, is doing his share of scientific work no less than he who is engaged in the more pleasing task of evolving new geologic principles. The masters of the science have not hesitated to turn their attention to economic problems. Clarence King deserves no less credit for his aid in opening up the west by economic investigations than for his contributions to knowledge on the age of the earth. We think of Major Powell as one of the founders of physiographic geology, but his memory will live rather for employing science to make available the latent fertility of the arid regions of the West. Surely no one will charge King or Powell with commercializing their science.

As I see it, there lies no danger in the present trend toward applied geology, provided our applied geology rests on a broad basis of scientific research. If the spring of pure science is cut off, the stream of applied geology must soon run dry. There is no field of pure geology which will not yield results applicable to questions of material welfare. On the other hand, any given investigation in applied geology may lead to problems of paleontology, petrography, geophysics, or other branches of pure science. In view of the pressing demand for results, we are justified in giving precedence to those fields of investigation which promise the earliest returns of material value. There is, however, grave danger that, carried away by the present furor for practical results, we may lose sight of our scientific ideals. Applied geology can only maintain its present high position of usefulness by continuing the researches which advance the knowledge of basic principles. Future progress in applied geology depends on progress in pure geology.

GEOLOGY.—*Note on the stratigraphy of east-central Idaho.* J. B. UMPLEBY, Geological Survey.

During recent field studies much additional information has been obtained concerning the stratigraphy of east-central Idaho. During September 1910 the writer examined the area about the head of Lemhi Valley, and a year later, in company with Dr. George H. Girty, revisited the locality about Gilmore and made a fairly complete collection of fossils.

The Paleozoic section at Gilmore is made up of a great succession of sedimentary rocks, striking north-south and usually dipping about 45° east. Cambrian, Ordovician, Silurian, Devonian (?) and Mississippian formations are present. At the base is a clear-white, fine-grained quartzite at least 2,000 feet thick. It is well exposed above Meadow Lake. Conformably above it is massive blue dolomitic limestone about 500 feet thick. This is assigned to the Richmond stage of the Ordovician. Then follows 300 feet of massive white dolomitic limestone of Silurian age. The formation next above comprises about 2,000 feet of thin-bedded blue and white dolomitic limestones, with occasionally a siliceous band. This formation is tentatively considered as Devonian. It is presumably conformable with the Mississippian, altho its upper contact was not seen. Only a portion of the latter formation is exposed, but from this it is known to be more than 300 feet thick.

The Paleozoic series rests upon intensely metamorphosed rocks of Algonkian age which outcrop along its western border. On the east it disappears beneath Miocene lake beds. Mesozoic formations are absent.

EVOLUTION.—*Evolution in discontinuous systems.* II[1]. ALFRED J. LOTKA. Communicated by J. A. Fleming.

One of the principal types of change of state with which we are concerned in discussing inter-group evolution in biological systems is the passage of matter from one kindred-group into another thru the process of "feeding," the one group serving as food for

[1] See this Journal 2: 2. 1912.

the other. Among the various possible cases of this kind we can distinguish the following:

1. A group A_1 feeds on living portions of a group A_h, which are either

(a) expressly killed in the act of feeding, or

(b) continue to live, at least for a time, while A_1 is parasitic upon them (parasites, disease germs).

2. The waste products A_H of a group A_h serve as food for A_1.

3. Several groups, such as A_1 and A_j feed competitively on the same group A_h.

Schematically we may represent these three cases by the following diagram

(1) $$A_h \rightarrow A_1 \rightarrow A_k$$

(2) $$A_h (\rightarrow A_H) \rightarrow A_1 \rightarrow A_k$$

(3) $$A_h \begin{matrix} \nearrow A_1 \rightarrow A_k \\ \searrow A_j \rightarrow A_l \end{matrix}$$

In the case of type (1) A_1 will as a rule tend to exert a prejudicial influence upon the growth of A_h. An exception occurs where there is symbiosis with mutual benefit, the term being here used in a general sense, to include for example the relation between man and farm plants and animals.

In the case of type (2) the influence of A_1 upon A_h will be rather beneficial than otherwise, since waste products are by the very nature of things more or less harmful to the group from which they originate. So long, however, as there is no undue crowding, so that the waste products are sufficiently spread out in space ("diluted"), this effect will as a rule be small, and may often be negligible.

Case (3) may be regarded as a special form of cases (1) and (2).

If we denote the mass of any given group by the letter M with the proper subscript, we may express in analytical form the statements made in the last three paragraphs. Arranging the facts in a table we have:

	$\frac{\partial}{\partial M_1}\left(\frac{dM_h}{dt}\right)$	
	COMMONLY	SPECIAL CASE
(1) $A_h \rightarrow A_1 \rightarrow A_k$	−	0 or +
(2) $A_h (\rightarrow A_H) \rightarrow A_1 \rightarrow A_k$	0 or +	

We now proceed to discuss in greater detail a case of the type (2) noted in our table:

$$A_h (\rightarrow A_H) \rightarrow A_1 \rightarrow$$

that is to say a kindred-group A_1 feeds on the waste products A_H of other groups which we denote collectively by A_h. Thus for example A_h may represent a number of carnivorous species, A_H the carbon dioxide and other matter excreted by them, and A_1 some green plant which assimilates such waste products, but is not itself consumed by A_h.

Fixing our attention first on A_1 we note that

$$\frac{dM_1}{dt} = B_1 - Z_1 \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where B_1 is the total food consumed by A_1 per unit of time, and Z_1 is the total waste matter (including the bodies of dead individuals) discarded by A_1 per unit of time.

We will write

$$\frac{dM_1}{dt} = (b_1 - z_1) M_1 = r_1 M_1 \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Similarly we have for A_H

$$\frac{dM_H}{dt} = B_H - Z_H \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

We will suppose that the groups A_h have had time to arrive at a state of equilibrium with their environment, and that the waste products A_H exert at most a negligible influence on A_h. Then we have for the mass M_h of the groups A_h

$$M_h = \text{constant} \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

This being so, the mass Z_h eliminated per unit of time by A_h will, under otherwise similar conditions, also be constant, so that

$$B_H = Z_h = \text{constant} \quad \ldots\ldots(5)$$

Again, Z_H the rate of elimination of mass per unit of time from A_H, stands in a simple relation to the rate of formation B_1 of A_1. If A_H lost mass only through A_1 feeding upon it, while on the other hand A_1 gained mass by feeding exclusively on A_H, we should have simply

$$Z_H = B_1 \quad \ldots\ldots(6)$$

In general we can not, however, suppose these conditions to be satisfied, so that we must introduce a coefficient θ, and write

$$Z_H = \theta B_1 = \theta b_1 M_1 \quad \ldots\ldots(7)$$

Substituting (7) in (3) we obtain

$$\frac{dM_H}{dt} = B_H - \theta b_1 M_1 \quad \ldots\ldots(8)$$

We are supposing all other conditions constant, and only M_H and M_1 changing. Under these circumstances b_1, r_1 and θ will be functions of M_H and M_1 alone

$$b_1 = b_1(M_H, M_1) \quad r_1 = r_1(M_H, M_1) \quad \theta = \theta(M_H, M_1) \quad \ldots\ldots(9)$$

Our immediate problem is to find a general solution of the set of differential equations (2) and (8), expressing M_H and M_1 as functions of t. For this purpose we will first of all simplify our notation by dropping all subscripts, and writing

$$M_H = X \qquad M_1 = Y \quad \ldots\ldots(10)$$

Equation (8) and (2) then assume the form

$$\frac{dX}{dt} = B - \theta b Y \quad \ldots\ldots(11)$$

$$\frac{dY}{dt} = rY \quad \ldots\ldots(12)$$

Let us expand the right hand member of (11) by Taylor's theorem in the neighborhood of the point X_∞ Y_∞ given by

$$\frac{dX}{dt} = B - \theta_\infty b_\infty Y_\infty = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots (13)$$

$$\frac{dY}{dt} = r_\infty Y_\infty = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots (14)$$

We thus obtain

$$\begin{aligned}(B - \theta b Y)^{\cdot} &= (B - \theta_\infty b_\infty Y_\infty) - \left\{\frac{\partial \theta b}{\partial X} \cdot Y_\infty\right\}(X - X_\infty) \\ &- \left\{\frac{\partial \theta b}{\partial Y} Y_\infty + \theta_\infty b_\infty\right\}(Y - Y_\infty) - \frac{1}{2}\left\{\left(\frac{\partial^2 \theta b}{\partial X^2} Y_\infty\right)(X - X_\infty)^2\right. \\ &+ 2\left(\frac{\partial^2 \theta b}{\partial X \partial Y} Y_\infty + \frac{\partial \theta b}{\partial X}\right)(X - X_\infty)(Y - Y_\infty) \\ &\left. + \left(\frac{\partial^2 \theta b}{\partial Y^2} Y_\infty + 2\frac{\partial \theta b}{\partial Y}\right)(Y - Y_\infty)^2\right\} - \ldots\ldots\ldots\ldots\ldots\ldots (15)\end{aligned}$$

or, in an obvious notation, and putting

$$(X - X_\infty) = x \quad \ldots\ldots\ldots\ldots\ldots\ldots (16)$$
$$(Y - Y_\infty) = y \quad \ldots\ldots\ldots\ldots\ldots\ldots (17)$$

$$\frac{dx}{dt} = \alpha x + \beta y + \gamma x^2 + \delta xy + \epsilon y^2 + \cdots \quad \ldots\ldots\ldots\ldots\ldots (18)$$

Similarly

$$\frac{dy}{dt} = \alpha' x + \beta' y + \gamma' x^2 + \delta' xy + \epsilon' y^2 + \cdots \quad \ldots\ldots\ldots\ldots\ldots (19)$$

The solution of the system of differential equations (18) (19) is

$$\begin{aligned}x &= A_1 e^{-ht} + B_1 e^{-kt} + A_2 e^{-2ht} + B_2 e^{-(h+k)t} + C_2 e^{-2kt} \\ &+ A_3 e^{-3ht} + B_3 e^{-(2h+k)t} + C_3 e^{-(h+2k)t} + D_3 e^{-3kt} + \cdots \quad \ldots\ldots (20) \\ y &= a_1 e^{-ht} + b_1 e^{-kt} + \cdots \quad \ldots\ldots\ldots\ldots\ldots\ldots (21)\end{aligned}$$

The values of h, k, A_1, A_2, . . . a_1, a_2, ... can be determined by substituting the solution in the original equation and equating the coefficients of homologous terms. It is unnec-

essary to carry this out in detail here; the expressions thus obtained for h and k are, however, of special interest

$$h = -\frac{1}{2}\left\{(\alpha+\beta') + \sqrt{(\alpha-\beta')^2+4\alpha'\beta}\right\} \quad \ldots\ldots\ldots(22)$$

$$k = -\frac{1}{2}\left\{(\alpha+\beta') - \sqrt{(\alpha-\beta')^2+4\alpha'\beta}\right\} \quad \ldots\ldots\ldots(23)$$

From these expressions it will be seen, that the solution becomes oscillatory as soon as

$$(\alpha-\beta')^2+4\alpha'\beta<0$$

It is then convenient to write the solution in trigonometric form, as follows

$$x=e^{-pt}\{A'_1\cos qt+B'_1\sin qt\}+e^{-2pt}\{A'_2\cos 2qt+B'_2\sin 2qt+C'_2\}$$
$$+e^{-3pt}\{A'_3\cos 3qt+B'_3\sin 3qt+C'_3\cos qt+D'_3\sin qt\}\ldots\ldots(24)$$

$$y=e^{-pt}\{a'_1\cos qt+b'_1\sin qt\}+\cdots\ldots\ldots\ldots(25)$$

where

$$p=-\frac{1}{2}(\alpha+\beta') \quad \text{and} \quad q=\frac{1}{2}\sqrt{-\left\{(\alpha-\beta')^2+4\alpha'\beta\right\}} \quad \ldots(26)$$

For lack of numerical data we can not apply the solution thus found to a concrete example of the particular case here considered. However, for a certain type of reaction, which the writer has discussed elsewhere,[2] the laws of chemical dynamics lead to a set of equations

$$-\frac{dx}{dt}=Lx+Ky+xy \quad \ldots\ldots\ldots\ldots\ldots\ldots(\text{I})$$

$$\frac{dy}{dt}=Lx+xy \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(\text{II})$$

which will be recognized as a special case of (18) (19); their solution is, in point of fact, of the form (20) (21) (24) (25).

In order to illustrate the character of the function represented by the series (24), a concrete example of such a reaction has been

[2] Jl. Phys. Chem. **25**: 271. 1910. Zeitschr. phys. Chem. **72**: 508. 1910. Only the first two terms of the series are given in these publications.

worked out, arbitrarily assuming the following values for the constants occurring in equations (I) and (II)

$$K = 0.505 \qquad L = 0.2$$

whence follows

$$p = 0.1 \qquad q = 0.302$$

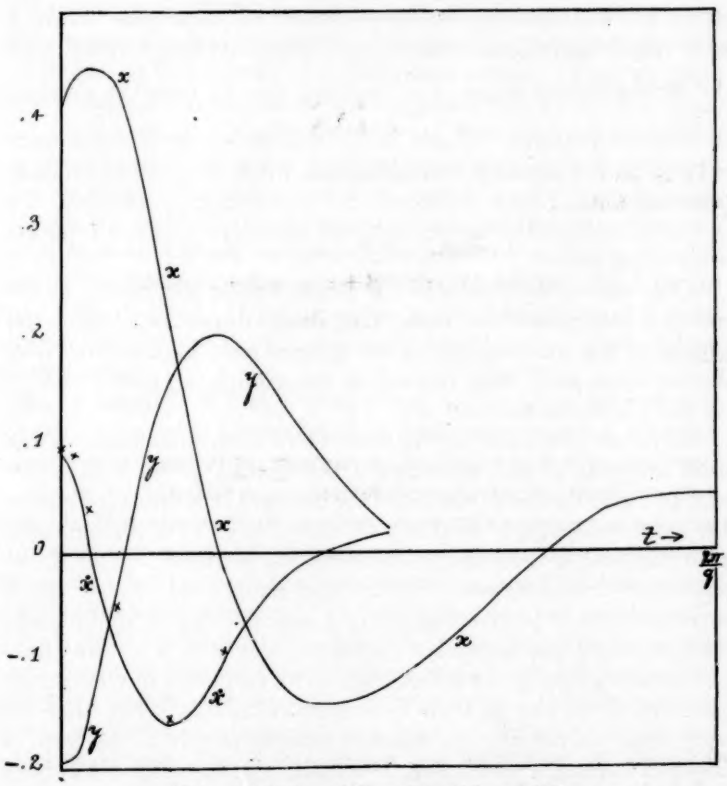

Fig. 1. Solution of Equations (24) and (25)

The first three terms of the solution were worked out. The constants thus obtained for x are tabulated below, together with the corresponding constants for y and $\dot{x}$.

	A_1	B_1	A_2	B_2	C_2	A_3	B_3	C_3	D_3
x	0.390	0.000	0.0385	0.1049	0.0454	−0.0611	0.0777	−0.00524	−0.0222
y	−0.077	.2329	−.0956	−.0438	.0298	− .0630	− .0780	.0118	− .00539
x	−0.039	− .1176	−.0556	−.0542	− .0091	.0886	.0320	− .00512	.00824

No attempt was made to investigate the convergence of the series, but the solution was tested by substituting it in the right hand member of (I) and comparing the values thus obtained with the corresponding values of $\frac{dx}{dt}$ obtained directly from the solution as tabulated above. These latter are shown as a continuous curve $\dot{x}$ in the accompanying diagram while the crosses indicate corresponding values obtained by substitution. Beyond the last cross shown the agreement was complete within the limits of plotting error.

While the curves shown in the diagram refer specifically to the reaction mentioned above, in their general appearance they are typical of the solution (25) of the general case, and we may here discuss them as if they related to the groups A_{H} and A_{I} which we have been considering.

We note, then, that at the start there is an abundance of the food material x, and accordingly the feeding group y increases rapidly, with the result that soon the increased consumption causes the total food supply to diminish, tho it is still for a time quite plentiful, and y accordingly continues to increase. After a certain time, however, when x, the food supply, has fallen below a certain value,[3] the feeding group y now also begins to diminish. This alternate rise and fall of the two curves, with a certain phase difference, would go on indefinitely if we extended our curves to infinity, for it can be seen by inspection of (24) (25), that for very large values of t the solution reduces simply to the form of damped harmonic oscillation. Actually the curve for x has been

[3] That this value happens to be zero is peculiar to the special case here considered, x being a factor of $\frac{dy}{dt}$ (see Equation II); in general this is not the case. To be precise, x represents not the food supply, but the excess of this over its equilibrium value. See Equation (16).

drawn for one entire fundamental period, and the curve for y for one-half-period.

The significance to a biological kindred-group of such alternating periods of prosperity and depression as are indicated in our oscillating curve, representing a function of the form (24) is so obvious as to call for no further comment. In particular, the question suggests itself to our minds, whether the curve of growth along which the human race is at present ascending, leads to a maximum, to be followed by a downward incline. That we have been living on our capital of natural resources is only too clear. But we are awakening to a realisation of this fact, and are taking stock, and looking ahead in preparation to meet such emergencies as may arise. Our reflections here lead us to the consideration of such topics as the preservation of our natural resources, the production of nitrogen compounds from the air, and the exploitation of the radiant energy received from the sun. These things have been discussed at length in the current scientific and technical literature, and their mere mention here in their logical place must suffice.

As an example of a case of the type (1. b) (page 50), we will consider a bacterial disease, such as pulmonary phthisis, which is more or less constantly present in the population (i.e., not epidemic in its occurrence). Brief reflection shows that we can apply to this case a mathematical treatment precisely analogous to that of the growth of a population. For we may think of the diseased part of the population as a separate aggregate, into which new individuals are recruited by fresh infection, just as new individuals enter an ordinary population by births. On the other hand members are continually eliminated from the aggregate, firstly by deaths, and secondly by recoveries. On the basis of these considerations formulae can without difficulty be established to express a relation between the total and the diseased population, which in this case is of more immediate interest than the ratio of the total mass of the population to that of the bacteria. Such general furmulæ however involve certain functions which are unknown, and whose determination by statistical methods would at best present great difficulties. The matter

assumes a somewhat more favorable aspect if we are satisfied with the discussion of the simple special case of a stationary population, in which the disease also is supposed to have reached equilibrium.

We may then proceed as follows:

Let N be the total number of the population, and
N_1 the number afflicted with the disease.

Let $S = Ns$ be the total number of deaths per unit of time, and let
$S_1 = N_1 s_1$ be the number of deaths per unit of time, due to the disease considered.

Let $N_1\sigma_1 = N_1 \frac{s_1}{\tau}$ be the total number of individuals eliminated from the aggregate of diseased persons per unit of time from all causes, including deaths by the disease under consideration, by other diseases, and also recoveries.

When a stationary condition is reached, σ_1 must be equal to the reciprocal of the mean duration L of the disease. In this case we have, then

$$N_1 s_1 = N_1 \frac{\tau}{L} \quad \ldots\ldots\ldots\ldots\ldots\ldots (27)$$

Furthermore, if γ is a factor indicating that fraction of the total deaths, which is due to the disease considered, then

$$N_1 s_1 = N_1 \frac{\tau}{L} = \gamma N s \quad \ldots\ldots\ldots\ldots\ldots\ldots (28)$$

Hence

$$\frac{N_1}{N} = \frac{\gamma L s}{\tau} \quad \ldots\ldots\ldots\ldots\ldots\ldots (29)$$

or, solving for L

$$L = \frac{N_1}{N} \frac{\tau}{\gamma s} \quad \ldots\ldots\ldots\ldots\ldots\ldots (30)$$

By the way of a numerical example, let us substitute in the formula thus obtained some data gathered from the statistics

for New York City. The supposition of a stationary population and an equilibrium condition of the disease is quite unwarranted here, but in the absence of more suitable material, and in view of the great uncertainty of the figures obtainable, we shall have to rest content with this very crude illustration.

In 1909 the total population of New York was about 4.5 millions. The total number of consumptives at the time has been estimated at about 45,000. Hence $\frac{N_1}{N} = 0.01$. The death rate per head, per annum, from all causes, was 0.016; that from tuberculosis alone 0.002. Hence

$$\begin{aligned} s &= 0.016 \\ \gamma s &= 0.002 \\ \gamma &= 0.125 \end{aligned}$$

The coefficient τ represents a measure of the "deadliness" of the disease, i.e., it expresses what fraction of the persons once struck with the disease untimately die therefrom. It is difficult to obtain any kind of estimate of the value of τ. We will assume that $\tau = 0.8$

We then have by (30)

$$L = \frac{0{,}01 \times 0{,}8}{0{,}002} = 4$$

In view of the crudity of the data on which it is based, this calculation must be regarded purely as an illustration of the principles involved, and not in any sense as an attempt to determine L, although the endeavor has been made to preserve at least the right order of magnitude in the example given.

The mathematical treatment of the phenomena presented by infectious diseases has been developed in some detail by Sir Ronald Ross, especially with respect to insect-carried diseases, in his book *The Prevention of Malaria*,[4] and, quite recently, in a paper published in *Nature*.[5]

[4] Published by Murray, 1910; Second Edition, 1911.

[5] "Some Quantitative Studies in Epidemiology," *Nature*, Oct. 5, p. 466. 1911.

PROCEEDINGS OF THE ACADEMY AND AFFILIATED SOCIETIES

THE BIOLOGICAL SOCIETY OF WASHINGTON

The 488th regular meeting was held at the Cosmos Club, November 18, 1911. Four new members were elected. The first communication was an illustrated paper on a *Study of distribution based upon the family Pyramidellidae*, by PAUL BARTSCH.

The second communication was entitled *The peculiar migration of the Evening Grosbeak*, by WELLS W. COOKE.

Most species of North American birds have migration routes that are approximately north and south, while the migration route of the Evening Grosbeak is nearly east and west.

The species is rather common in the mountainous parts of western North America from central Alberta to southern Mexico. It has been divided into three farms: *montana* includes all the breeding birds of the United States and southern British Columbia; *mexicana*, all the breeding birds of Mexico; and *vespertina*, the remainder of the breeding birds of Canada.

The species was originally described from migrants taken in April, 1823, at Sault Ste. Marie, Mich., but it was more than half a century later before the first eggs were found. The first published description of the eggs was by Bryant in 1887 of a set found May 10, 1886, in Yolo County, Calif. A set of eggs had been taken two years earlier at Springerville, Ariz., but an account of it was not published until 1888. Ten years elapsed before the next set was taken in 1896 near Lake Tahoe, Calif. There had been only three sets found, therefore, up to 1901, when Mr. F. J. Birtwell found at Willis, N. M., five nests in one small colony. He secured the eggs from two of the nests and lost his life by an accident in climbing after the third. Only a few nests have been found in the last ten years, so that there are scarcely a dozen sets of the eggs of the Evening Grosbeak in existence at the present time. All of these eggs belong to the subspecies *montana;* the eggs of the type species *vespertina* are still unknown to science, although young have been found in the nest.

The form *montana* is not migratory in the strict sense of the word. It nests in the mountains and spreads out in winter time into the valleys and the neighboring plains. The form *vespertina*, nesting entirely north of the United States in the mountains of Alberta, is strongly migratory, but instead of moving south in the fall, which would bring it into the district occupied throughout the year by *montana*, it journeys eastward and is a common winter visitant in Manitoba and Minnesota. Hence it spreads less commonly to Iowa, Wisconsin, Michigan and western Ontario. The species was scarcely known further east until the winter of 1889–90, when a remarkable invasion of the Evening Grosbeak was noted throughout much of the northeastern United States. So numerous were they that more than a thousand were killed in the vicinity of

Fig. 1. Evening Grosbeak
● Breeding
○ Winter
Heavy line separates *montana* from *vespertina* on the north and *mexicana* on the south.

Toronto, Ontario, and the birds for the first time appeared in New England. Ten were seen in this part of the country for the next ten years, but during the last few years they have become increasingly common and the winters of 1909–1910 and 1910–11 witnessed the presence of almost as many individuals as had appeared twenty years earlier.

The species is known to have ranged east, southeast and south to the city of Quebec, Canada, Bucksport, Me., Seabrook, N. H., Cape Cod, Mass., Woonsocket, R. I., Portland, Conn., Fairhaven, N. J., Williamsport, Pa., Granville, O., Hickman, Ky., New Haven, Mo., Onaga, Kans., and Ellis, Kans.

During the invasion of 1889–90, the birds remained until May 1, the last being seen on that date at Henniker, N. H. During 1910–11, they remained until May 15 at Leominster, Mass.

Not all of the migrants go eastward, for the Evening Grosbeaks of Sundance, Wyo., belong to the Canadian farm, *vespertina*, and must have made a long migration from Alberta; though *montana* breeds but a short distance to the westward.

D. E. LANTZ, *Recording Secretary.*

PROGRAMS AND ANNOUNCEMENTS

BIOLOGICAL SOCIETY OF WASHINGTON

The 492nd meeting will be held at the Cosmos Club at 8 p.m. Saturday, January 20, 1912. Program: Brief notes and exhibition of specimens. *Elk heads in Jackson Hole, Wyoming;* illustrated; E. A. PREBLE. *A naturalist among the Igorotes of the Philippine Islands;* illustrated; H. V. HARLAN.